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L. L. MERRILL
D. HORD

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NAVAL HEALTH RESEARCH CENTER
P.O. BOX 85122
SAN DIEGO, CALIFORNIA 92138

NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
BETHESDA, MARYLAND

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Lex L. Merrill

David Hord

Naval Health Research Center

PO Box 85122

San Diego, California 92138-9174

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Summary

Military personnel must often make decisions quickly, and the results of those decisions are often of critical importance. A technique is needed that can monitor the cognitive activity of personnel, and indirectly assess decision-making ability. Such a technique may lead to a more effective combat force by relating a covert indicator of personnel cognitive functioning. Small decrements in decision-making ability may be measured by event-related brain potentials (ERPs) before they are behaviorally observed. ERPs have gained some credibility as indicators of the timing and strength of cognitive events (Donchin, Kramer, & Wickens, 1986).

The Integrated Area Measure (IAM) of ERP components was evaluated as a sensitive and easy-to-use measure of cognitive function that does not require complicated computer algorithms (Coles et al., 1986). Additionally, a hypothesis that the right hemisphere of the brain plays a dominant role in the discrimination of visual stimuli was assessed (Miskin & Appenzeller, 1987).

One hundred and two, U. S. Navy sonar school students and instructors were used as subjects. As the subjects completed two visual tasks, brain electrical activity was recorded, at the scalp, and at the left and right hemispheres (C3 and C4).

The results indicate that the IAM did not measure an interhemispheric difference when the subjects were required to discriminate stimuli. However, the right hemisphere IAM was significantly larger when the subjects were required to discriminate stimuli, and remember the number of selected stimuli. This may indicate that the right hemisphere generates the activity required for the updating of working memory which is believed to be located in the left hemisphere. The IAM may ultimately prove to be a useful tool for monitoring the cognitive activity of personnel.

Introduction

Due to the instantaneous and often critical cognitive decision-making responsibilities that have been placed upon combat systems operators, the consequences of subtle cognitive performance decrements may lead to a less effective combat force. Therefore, methods are needed to evaluate the on-line efficiency of the cognitive functioning of such personnel. Psychophysiologists have recently discovered correlates of incremental cognitive decision-making activity within the morphology of the event-related potential (ERP) (Donchin, Kramer, & Wickens, 1986). At the present time, however, the quantification of this activity relies upon subjective interpretation or the use of complicated computer algorithms. Subjective interpretations are unreliable and inconsistent, and computer algorithms are complicated and time-consuming. The present study is an attempt to aid in solving these problems by providing a practical method for evaluating the cognitive efficiency of critical systems operators.

The present study is concerned with the quantification of cognitive workload by means of ERPs. The P300 ERP component is the component that is most often used as an indicator of cognitive workload (Donchin et al., 1986). Therefore, a review of the literature is provided that relates the processes that have been associated with the P300 component, and the quantification of ERPs in general.

Background

ERPs are a computer-enhanced summation of brain electrical responses to a series of identical stimuli. The procedure for gathering ERPs is similar to that employed in general electroencephalography (EEG) work. Methods for gathering ERPs differ to some degree; however, basic to most methods is the attachment of electrodes to the subject's scalp at sites which have been agreed upon by the scientific community (Jasper, 1958). After the electrodes are attached, a brief stimulus, such as a flash of light, is presented to the subject. The stimulus evokes an electrical brain response which is conducted through the electrode into specially configured amplifiers and filters.

Finally, each response is stored in a computer where, after a predesignated number have been gathered, the total number of responses are calculated, and a single record is produced that represents that portion of the subject's stimulus-related brain electrical activity. Averaging increases the signal to noise ratio, and, therefore, a more legible record is obtained. By convention, the various peaks and valleys of the waveform are labelled "components" and are defined by their post-stimulus latency in milliseconds (ms) and amplitude in microvolts (uv).

Although most ERP studies use the amplitude and latency of components to gauge the effect of a variable on the ERP, other measures have also been employed. One such measure is the integrated area measure (IAM). For the present study, the IAM was computed by dividing each subject's averaged ERP into 256 vertical sections. The ERP then had an amplitude measure approximately every 1.95 ms. The amplitude of these points was algebraically summed, and was defined as the IAM. The impetus for this study evolved during a search for an ERP predictor of performance. During that search, it became obvious that the integrated area measure (IAM) had the following, previously reported, advantages over traditional methods of measurement: (1) The IAM, which is a function of both amplitude and latency, has less variance; (2) it lessens the need for complicated algorithmic computer programs; (3) the IAM is not subject to small changes in latency (latency jitter); and (4) the IAM minimizes the effect of random amplitude fluctuations within given time parameters (Coles, Gratton, Kramer, & Miller, 1986). In addition, the literature strongly supports the notion that the magnitude of the later positive component is proportional to the degree of cognitive workload (Wickens, Isreal, & Donchin, 1980; Donchin, Kramer, & Wickens, 1986; Wickens, Isreal, & Donchin, 1977); therefore, it seems reasonable to expect that the IAM would also be proportional to cognitive workload.

The present study attempts to distinguish between levels of cognitive workload, as related to the functioning of the cerebral hemispheres, and, therefore, possibly be of use in the monitoring of personnel. Of special interest are personnel who must monitor displays, such as sonarmen, air traffic control personnel, and aviators. Small decrements in their cognitive performance cannot be deduced through behavioral observation, but may be seen within an ERP paradigm (Donchin et al., 1986). Small decrements in cognitive performance may be of critical importance especially during combat operations.

Although the term, "integrated area measure," has been previously cited (Callaway, 1975; Coles et al., 1986; Lewis & Sorenson, 1987), only one study (Rosler, 1981) utilized the integrated area measure, as it is defined in this study, within an experimental design. Rosler used a design that incorporated a stimulus-discrimination learning task, and found that a short-term habituation/facilitation effect could be gauged through the use of an IAM.

A definition of cognitive workload that will be broadly accepted by the scientific community appears not to be forthcoming (Moray, 1979; Wickens, 1984). However, Broadbent (1958) characterized the human capacity to process information as limited, and such a limited processor, under increased task demands, would be expected to exhibit signs of increased cognitive workload. Therefore, cognitive workload is defined as, "that portion of the operator's limited capacity actually required to perform a particular task," and that, "the objective of a workload measurement is to specify the amount of expended capacity," (O'Donnell & Eggemeier, 1986). As the subject is required to perform more difficult tasks, it seems reasonable to assume that an increasing amount of cognitive resources will be required to successfully complete the task (Norman & Bobrow, 1975). As cognitive workload increases, the neural systems involved become increasingly activated, and this increased activity may possibly be quantified by ERP measurements.

Of the many studies that have considered the merits of the various methods of analyzing averaged data (Callaway, 1975; Childers, Aunon, & McGillen, 1981; O'Connor, Simon, & Tasman, 1984; Daruna & Karrer, 1981; Schacter, Lachin, Kerr, & Wimberly, 1976; Woods & McCarthy, 1984), all appear to agree that no method yet exists that would satisfy the three basic criteria cited by Donchin (1969) of reliability, objectivity, and ease-of-use. The analysis of averaged ERP data involves the visual inspection of the morphology of the waveform followed by the measurement of the peak-to-peak amplitudes and latencies. These techniques are subject to the extremes of subjectivity and interrater unreliability, and, therefore, little consistency can be expected (Callaway, 1975; Donchin, 1969).

Endogenous components, those components that are generated in response to cognitive activity, are of primary interest in ERP studies that attempt to link components of the ERP waveform to cognitive activity. Two basic parameters of ERP measurement may have an effect on the total IAM. First, any activity that results in a change in the amplitude of the ERP waveform will change the IAM and second, any activity that results in a change in the latency of the amplitude will change the total IAM. Because the effect of varying levels of cognitive workload on the ERP waveform is being investigated, and since the P300 component is commonly acknowledged as the dominant indicator of cognitive workload, only those factors that influence the amplitude and latency of the P300 component were considered.

P300

The P300 component has been defined in various ways. For example, it has been labelled the component that, "...reaches peak amplitude in the vicinity of 300 ms," (Sutton, 1969, p. 240); the positive component with a latency of 300 ms to 500 ms (Vaughn, 1969); a positive component that has a latency of 300 ms to 900 ms (Kutas & Hillyard, 1984); a positive component with a latency of 300 to 750 ms (Donchin, Kramer, & Wickens, 1986); and, "...the largest positive-going peak...after the N1-P2-N2 complex between 240 ms and 350 ms...," (Polich, 1987, p. 42). This study defines the P300 component as a positive-going wave that reaches peak amplitude between 250 and 500 ms.

P300 Amplitude

Donchin, Ritter, & McCallum (1978), Duncan-Johnson (1979), Pritchard (1981), and Johnson (1986) have provided excellent reviews of the literature concerning the factors which influence the amplitude of the P300 component. Johnson (1986) states that most of the studies that have investigated the variation in P300 amplitude have relied on a variety of constructs that can reasonably be reduced to three categories or dimensions: (1) subjective probability, (2) stimulus meaning, and (3) information transmission. Johnson believes that the amplitude of the P300 component is a function of the amount of transmitted information, times the subjective probability, plus the stimulus meaning. The effect of subjective probability, however, has been shown to be modified by the length of the interstimulus interval (McCarthy & Donchin, 1976). Generally, it appears that the effect of subjective probability occurs when an interstimulus interval of between 1500 ms and 2000 ms is employed (Duncan-Johnson & Donchin, 1977). The amplitude of the P300 decreases with increasing interstimulus intervals (McCarthy & Donchin, 1976). Finally, Donchin et al. (1986) have shown that the amplitude of the P300 is sensitive to different levels of skill development and cognitive workload.

The concept of working memory (Baddeley & Hitch, 1974; Donchin et al., 1986) may also be a factor that will contribute to variation in the IAM. Johnson (1986) did not discuss this concept, but it is a dimension of cognitive functioning that affects the amplitude of the P300, and is important to the monitoring of central nervous system functioning. Working memory is similar to the commonly used term, "short-term memory." Working memory, however, has a dynamic connotation. It interacts with incoming stimuli, it retains percepts of pertinent environmental stimuli for short periods of time, and it can be thought of as the cognitive component for processing information (Klein, Coles, & Donchin, 1983; Waldrop, 1987).

P300 Latency

Duncan-Johnson (1981), Duncan-Johnson & Donchin (1982), and Donchin et al. (1986) have provided excellent P300 latency literature reviews. Overall, the latency of the P300 component is proportional to the duration of task-relevant stimulus recognition and evaluation processes (Duncan-Johnson & Donchin, 1982; Donchin, et al. 1986). More specifically, Duncan-Johnson and Donchin (1982) have stated that the, "...latency of the P300 depends on the time required to identify the stimulus, evaluate its relevance to the task, and assess its expectancy...," (p. 11). Four factors appear to affect how long it takes an observer to recognize and evaluate stimuli: (1) the probability of a stimulus (Duncan-Johnson & Donchin, 1982); (2) the difficulty of discriminating a stimulus (Kutas, McCarthy, & Donchin, 1977;

Squires, N., Donchin, Squires, K., & Grossberg, 1977; Duncan-Johnson & Kopell, 1981); (3) the memory load requirements (Heffley, Wickens, & Donchin, 1978; Ford, Mohs, Pfefferbaum, & Kopell, 1980; Gomer, Spicuzza, & O'Donnel, 1976; Kramer, Fisk, & Schneider, 1983), or the memory set size (Adam & Collins, 1978); and (4) the type of task or test being administered, i.e., power or speed (Wickelgren, 1977).

The more probable the occurrence of a task-relevant stimulus, the shorter will be the time required to discriminate and evaluate the stimulus. This factor, however, may be modified by the difficulty of discriminating the relevant stimulus. Difficulty has been manipulated in two basic ways: first, by increasing the number of distractors (Heffley et al., 1978), and secondly, by decreasing the number of discriminating parameters (Squires et al., 1977; Kutas et al., 1977; Duncan-Johnson & Kopell, 1981).

The present study is concerned with the effects of the process of working memory, which may be differentially related to hemispheric cognitive functioning. As previously cited, memory load is positively related to the latency of the P300. Therefore, it would seem probable that an increase in the IAM would occur following the stimulus discrimination and evaluation processes.

An additional concern is the question of which hemisphere would provide a maximal association between the IAM, and discrimination and evaluation processes. The work of Gazzaniga and LeDoux (1978), and of Mishkin and Appenzeller (1987) strongly suggest that in both animals and humans the right hemisphere is more involved in visual information processing than the left hemisphere.

Two specific hypotheses, regarding the relationship between the area under the ERP waveform, cognitive workload, and hemisphericity, will be addressed. The hypotheses are: (1) The area under the ERP waveform from 0-500 ms is proportional to the degree of cognitive workload. Specifically, the mean group IAM is the least for a noncontingent baseline task, intermittent for a discrimination only task, and greatest for a discrimination plus memory task; and (2) the right hemisphere will show a greater IAM than the left hemisphere.

Methods

Subjects.

One hundred and two, male U.S Navy sonar school instructors and students from the Anti-Submarine Warfare School, San Diego, California, volunteered as subjects. The mean age of the sample was 22.6 years (S.D. = 4.0), with a range of 18 to 37 years. The mean sonar display experience level of the sample was 1.87 years (S.D. = 2.97), with a range of 0 to 19 years.

Procedure.

Each subject completed two sessions of two visual "oddball" tasks (Donchin, 1981). The first session of each task was a practice session. While performing the tasks, the subject sat approximately 36 inches from a 12-inch video screen. A checkerboard pattern, composed of 7/16" black and white squares, was used. In the first task, the presentation of the patterns consisted of one pattern followed by the reverse of the pattern, i.e., black squares would be replaced by white squares and vice versa. Each pattern was displayed for one second, and the subject was simply instructed to look at the screen. This task was labelled the noncontingent baseline (B). In the second task, the same checkerboard pattern was used with an 80/20 paradigm. Each subject completed 150 trials. Each pattern was displayed for 500 ms, and the interstimulus interval randomly varied from 400 to 600 ms, averaging 500 ms. On 120 (80%) of the trials, the pattern remained constant, and on 30 (20%) of the trials, the pattern reversed. When the patterns remained constant, they were labelled non-targets, and when the patterns reversed, they were labelled targets. The subjects were instructed to remember the number of target trials, and to report the total when the task was completed. When the subject was presented a non-target trial, the task was labelled discrimination (D). On this portion of the overall task, the subject had to discriminate the non-targets from the targets. The target trials were randomly intermixed among the non-target trials. The pattern was reversed for the target trials. This portion of the task was labelled discrimination memory (DM). On this part of the overall task, the subject had to discriminate the targets from the non-targets, and increment an internal counter requiring the use of memory.

EEG Recording.

Grass silver cup electrodes were attached to the scalp at C3 and C4 (lateral parietal) according to the International 10-20 System (Jasper, 1958), and referenced to linked mastoids. The C3 and C4 sites were chosen to test the second hypothesis regarding lateral asymmetry. Impedances were 5K ohms or less. The EEG was amplified (x 20,000) by a Grass Model 12A5 amplifier. A DEC MINC 11/23 computer digitized the 500 ms sweeps time locked to all the trials. The signal averaged ERPs were then obtained for each subject.

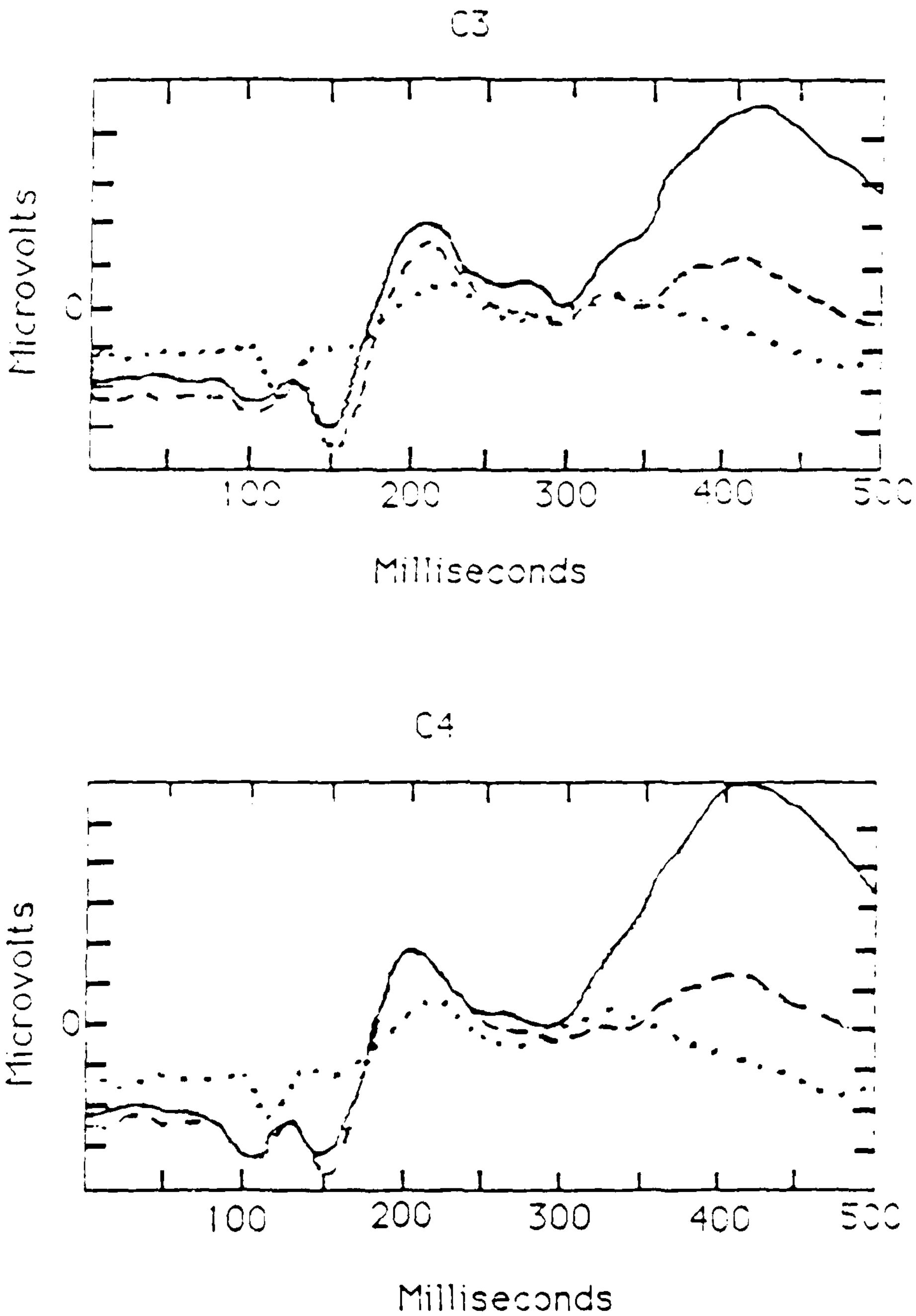
Data Reduction.

Grand means for each task were determined (see Figure 1). From these it was hypothesized that the integral of the area under the curve, labelled the IAM area, increased proportionally from task B to task D to task AM.

The calculation of the integrated area was accomplished by dividing each subject's averaged ERP into 256 vertical sections. The ERP would then have an amplitude measure approximately every 1.95 ms. The amplitude of these points was algebraically summed, and was defined as the IAM.

Results

The independent variables are the three levels of cognitive workload (B, D, and AM). The dependent variable is the IAM. The means, standard deviations, ranges, and the summary of the analysis of variance of the three cognitive loads by site is shown in Table 1.



Baseline . . . .

Discrimination - - - - - - - - - - -

Discrimination Memory ————————

Figure 1. The grand means for the three levels of cognitive workload.

TABLE 1 - MEANS, STANDARD DEVIATIONS, AND RANGES FOR THE INTEGRATED AREAS

Cognitive Load	Hemisphere	Mean	S.D.	Range
B	Left	138	216	-0416 - 0800
	Right	140	255	-1471 - 0785
D	Left	392	318	-0314 - 1862
	Right	404	304	-0351 - 1513
DM	Left	569	425	-0166 - 2109
	Right	668	447	0024 - 2046

SUMMARY OF ANALYSIS OF VARIANCE

Source	f	p
Cognitive Load	82.47	.0001
Hemisphere	6.66	.01
Cognitive Load x Hemisphere	6.98	.01

It can be seen that a significant main effect was found for cognitive load and hemisphere. As can be seen in Figure 2, there was an interaction for the discrimination memory measure.

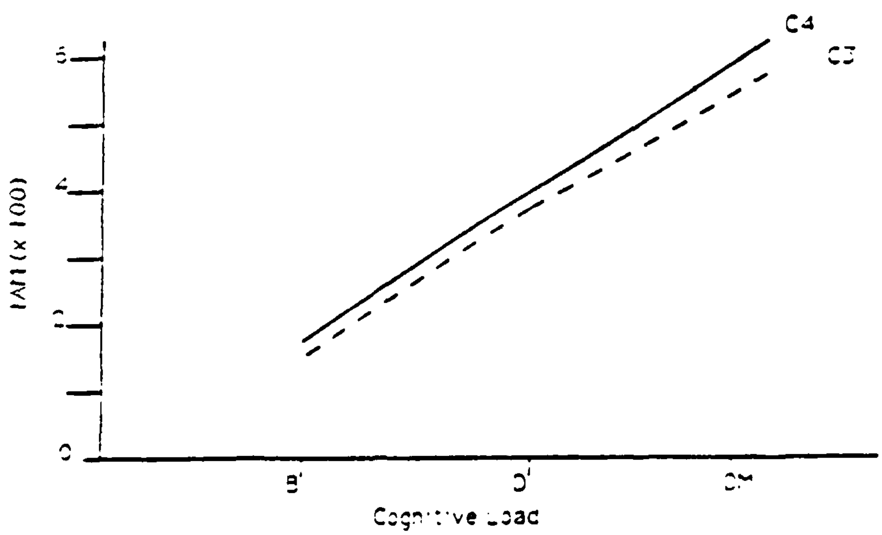


Figure 2. THE IAM AS A FUNCTION OF COGNITIVE WORKLOAD

Multiple t-test comparisons were done in order to obtain a more definitive picture of the various integrated areas measures, and the results can be seen in Table 2.

TABLE 2 - SELECTED T-TESTS FOR THE INTEGRATED AREAS MEASURE.

Variables	t Value	2-Tail Probability
B C3, B C4	0.08	N.S. (hemi)
B C3, D C3	7.52	< .01 (cog)
B C4, D C4	7.54	< .01 (cog)
D C3, D C4	0.81	N.S. (hemi)
D C3, DM C3	5.19	< .01 (cog)
D C4, DM C4	6.79	< .01 (cog)
DM C3, DM C4	3.31	< .01 (hemi)

C3 = Left Hemisphere
C4 = Right Hemisphere
hemi = hemisphericity
cog = cognitive load

A Bonferroni test was applied to allow for multiple t-tests. These results show a nonsignificant difference between hemispheres for the baseline task, a significant difference between the baseline and discrimination task within hemispheres, a nonsignificant difference between hemispheres for the discrimination task, a significant difference between the discrimination and discrimination memory tasks within hemispheres, and a significant difference between hemispheres for the discrimination memory task.

Discussion

Overall, the results of this study indicate that the area under the ERP wave is related to cognitive workload. More specifically, the area is greater in the right hemisphere for the DM task. The integrated area was not significantly greater between hemispheres for the B and D tasks. Since the hemispheric differences were not significant for the baseline and the discrimination tasks, it's possible that the hemispheres were playing an equal role in such processing demands. This would contradict the Gazzaniga and LeDoux (1978) conclusion that the right hemisphere plays a dominant role in visual discrimination. The right hemisphere appears to generate the required activity for the updating of working memory. The left hemisphere could then be viewed as the passive receptor of information that is later used for verbal production.

The present study incorporated within its design the "oddball" paradigm wherein the task relevant event occurred, randomly, on 20% of the stimulus presentations. This surprising event would be expected to increase the amplitude of the P300 component, and therefore, the integrated area measure. A mediating factor, however, was the use of a 500 ms interstimulus interval. It has been shown that the effect of subjective probability seems to occur only when the interstimulus interval is between about 1500 ms and 2000 ms (Donchin, 1981; McCarthy & Donchin, 1976). Since a 500 ms interstimulus interval was used, the effect of the subjective probability factor was attenuated.

Because the IAM is the result of a measurement between a constant set of temporal parameters employed by the computer, they are not free to vary according to the post hoc judgment of the experimenter, and therefore, it appears that the IAM can be reliably used by many different experimenters. Also, as the IAM procedure yields one value for the entire ERP, as opposed to the set of measures of amplitudes and latencies given by other procedures, the interpretation of the IAM can be expected to show less variability across sessions and laboratories. The IAM appears to be an event-related brain potential measure that may be "reliable, objective, and easy-to-use."

Figure 1 shows that the area from about 300-500 ms is most affected by the demands of the different tasks. This supports the assumptions made from the literature (e.g. Duncan-Johnson, 1981; Johnson, 1986) that the P300 is the dominant indicator of cognitive activity. The IAM, then, seems to be mainly a measure of the activity from about 300 ms to 500 ms.

In summary, the hypotheses of this study were confirmed. There was a significant difference in the IAM between cognitive tasks. The hemispheric difference was specific for the discrimination memory task. A conjecture that has been made is that this effect was due to the working memory requirements of the task.

Future studies that use the IAM as an index of cognitive activity could possibly profit by simply integrating the area from 300-600 ms. Using the area from 300 ms to 600 ms would be justified from the examination of Figure 1, where it can be seen that the P300 component has not completed its entire cycle at 500 ms. This would be a more definitive measure of certain cognitive activity, and is the area most discussed in the ERP literature. An even finer discrimination of activity could possibly be done by integrating only the positive area from 300-600 ms. This would eliminate the unknown effect that subtracting the negative area of the curve has on the final IAM. It would also be of value to know whether a central site, Fz-Pz-Cz, would be as accurate in discriminating cognitive activity as the C3 and C4. If one central site is an accurate gauge, then it would reduce the number of sites and simplify the attachment of monitoring devices. Future studies should also attempt to remedy the methodological weaknesses of the present study. These include the absence of a pre-stimulus baseline and the difference in stimulus duration time between the baseline task and the "oddball" task.

The IAM may ultimately prove to be a useful tool for monitoring the cognitive activity of personnel. One future scenario could involve the presentation of a randomly presented cognitive task to monitored sonarmen, radarmen, and air traffic control personnel. The computer would then provide a readout of three IAM's. These measures could be either positive or negative values. The first measure would be from 0 to 100 ms and would gauge the person's basic physiological functioning (Goff, Allison, & Vaughn, 1978). The second integral, from 100 to 300 ms, would be an indicator of the functioning of the attentional system of the person (Hillyard & Hansen, 1986). Finally, the IAM integral from 300-500 ms would provide an index of the person's cognitive efficiency (Donchin, et al, 1986).

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The Integrated Area Measure (IAM) of ERP components was assessed as a simple method of quantifying cognitive workload. Additionally, the hypothesis of Miskin and Appenzeller that the right hemisphere is more involved in visual processing than the left was evaluated. One hundred and two U.S. Navymen were used as subjects and each subject completed a baseline and an "oddball" visual task. EEG was recorded at two electrode sites (C3 and C4). The results indicate that the IAM may be useful as a measure of cognitive workload. The IAM showed that stimulus discrimination was not greater for the right hemisphere, therefore, the hypothesis of Miskin and Appenzeller was not supported. However, the IAM for the right hemisphere was significantly larger than the left hemisphere measure for discrimination memory. The present data may suggest that the right hemisphere generates the required activity for the updating of working memory. The IAM may ultimately prove to be a useful tool for monitoring the cognitive activity of personnel.

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